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Abstract

An examination of the characteristics model shows that declining marginal utility is part of the sufficient conditions to obtain a unique solution, although many food consumption studies have ignored this requirement. Implications of this condition are incorporated into the hedonic price equation. The Box-Cox technique is used to estimate the hedonic price equation using the 1977-78 NFCS. Results are compared to the theoretical conditions. Inferences drawn suggest that the theoretical constraints hold for the samples used.

Key Words: Box-Cox regression, characteristics model, demand, food demand, hedonic price equation, nutrients.

Introduction

Increased attention to their diets and changes in relative prices have caused American consumers to change the types of foods they purchase. Descriptive analyses of food consumption indicate that significant changes have occurred, especially in recent years, and that wide variations in food expenditures, consumption, and nutritional intakes exist (e.g., Adrian and Daniel 1976; Allen and Gadson 1983; Buse 1986; Capps 1986; Capps and Senauer 1986; Chavas and Yeung 1982; Eastwood, Brooker, and Terry 1986; Peterkin and Kerr 1982; Peterkin, Kerr, and Hama 1982; Price *et al.* 1976; and Tippet and Riddick 1987). Surveys of consumer attitudes continue to find evidence of consumer interest in the nutritional content of foods (e.g., Vance Research Services 1989).

Concern with these issues is not misplaced in light of the emerging information about relationships between diet and health. Some major public assistance programs focus on diets, including the school lunch and food stamps programs and aid to families with dependent children or to women, infants, and children. Other agriculture-related programs, especially those directed at the farm and food distribution levels, affect absolute and relative food prices, and consequently food consumption. If dietary levels are to be improved and if more effective public programs are to be implemented, then it is necessary to learn more about consumer behavior and the interrelationships among food purchases, nutrition, preferences, income, and prices.

Economists have developed three theoretical approaches to the analysis of consumer purchases. They vary in their potential for incorporating attributes like nutrients. Classical demand theory assumes that consumers derive satisfaction directly from market goods. Solving this utility maximization problem leads to equations in which prices, income, and socioeconomic variables determine the quantities demanded. It is difficult to extend this approach for the purposes at hand because there is little opportunity to modify the relationships to introduce product characteristics.

A second approach is the household production model (Becker 1965). This model assumes consumers transform marketplace goods into commodities that generate utility via household resource allocation (e.g., a meal produced with a kitchen, food, and household time). Solving this utility maximization problem also leads to equations that are not amenable to the introduction of attributes as part of the decision of which foods to purchase.

The characteristics model is the third approach. It assumes that consumers derive utility from the physical properties that market goods possess. This assumption causes the arguments of the utility function to be attributes rather than goods or commodities. Consequently, the portrayal of decision making explicitly incorporates characteristics. The solution of the model includes a behavioral equation that relates the market price of a good to the attributes it contains. As a result, this model is most appropriate for the analysis of decision making with respect to consumer goods and their characteristics. One dimension of food attributes is the nutritional content, so nutrients are part of the utility maximization process. Solving this model yields an equation in which the market price of a food is a function of its nutritional content.

Objectives

Although the theoretical framework of the characteristics model has been established and various empirical applications have occurred, the ties between the theory and estimation are strained with respect to food demand. A particularly troublesome problem is the generation of an empirical counterpart of the behavioral equation that relates market prices to consumer valuations of nutrients—the hedonic price equation. The overall goal of this project was to examine the theoretical properties of the utility maximization problem to generate a hedonic price equation that can be used to test the theoretical constraints. Specific research objectives to attain this goal were:

1. to provide an overview of relevant characteristics theory models;
2. to identify the necessary and sufficient mathematical properties of the characteristics model that are consistent with economic theory;
3. to examine the assumption of declining marginal utility;
4. to apply the Box-Cox functional form to the hedonic price equation and to derive the theoretical restrictions on the parameters of this relationship;
5. to test the theoretical restrictions on the Box-Cox functional form.

The Characteristics Model

Waugh (1928, 1929) conducted the initial work on demand analysis that focuses on product characteristics. His research examined quality attributes of vegetables. Measures of quality used in the study were color, size, shape, and condition of locally grown vegetables in the Boston wholesale market. Clark and Bressler (1938) studied strawberry and egg prices as functions of size, condition, uniformity, color, and variety. Recently, Jordan *et al.* (1985) examined wholesale-level valuations of fresh tomato characteristics including size, damage, color, and firmness.

Durable goods also have been analyzed from the characteristics' perspective. Automobile prices have been expressed as linear functions of attributes (e.g., Adelman and Griliches 1961; Court 1939; Dhrymes 1971; and Ladd and Zober 1977). Refrigerator prices have been expressed as functions of height, weight, and freezer capacity (Dhrymes 1971). Fettig (1963) related tractor prices to horsepower and type of engine. The characteristics approach has also been used to study housing markets (Bartik 1987; Epple 1987; Freeman 1979; King 1976; McConnell and Phipps 1985; Palmquist 1984; and Witte, Sumka, and Erekson 1979).

Explicit incorporation of product characteristics into theoretical models that examine the utility maximization process began with the work of Houthakker (1951-52) and Theil (1951-52). A second approach was developed by Lancaster (1966). Recent extensions of the Lancaster model have been applied to the nutritional analysis of food demand. Most of these applications have weak links to the theoretical constraints associated with unique solutions of the models. Consequently, attention focuses on the structure of these models. But in order to gain a perspective on the similarities and differences among the types of characteristics models, the discussion begins with an overview of the two major approaches and then turns to a more detailed presentation of the type that has been used frequently in the nutritional analysis of food demand.

Houthakker-Theil

The inclusion of product attributes in the utility function begins with the works of Houthakker (1951-52) and Theil (1951-52). Houthakker assumes the consumer's utility function has both quantities of goods and their qualities as arguments. His model assigns only one quality variable to each good. The price of each product is disaggregated into quantity and quality components.

$U = u(q_1,\dots,q_n,v_1,\dots,v_n).$

$M = \sum_{i=1}^{n} p_i\, q_i.$

U = utility;

q_i = quantity of the ith good consumed;

v_i = is the quality of the ith good;

p_i = market price of the ith good;

$p_i = a_i + b_i\, v_i$;

a_i = quantity price of the ith good;

b_i = quality price of the ith good;

n = number of goods.

The utility function is assumed to be increasing, convex in (q_i,v_i), and twice continuously differentiable. This model divides the consumer's decision into two steps: 1) the consumer chooses the product to purchase and 2) the consumer decides how much money to spend on quality. Products with different characteristics are considered to be the same good, only differing by the respective v_i measure.

Theil (1951-52) presents a model that is quite similar. His utility function has quantity and quality as arguments, but the latter is represented as a vector of characteristics. The price equation is slightly different in that the market price is an increasing function of quality.

$U = u(q_1,\ldots,q_n,z_1,\ldots,z_n).$
$p_i = p_i(z_i).$
z_i = vector of qualities of the ith good.

Both models treat substitute goods as the same generalized product having a continuous spectrum of qualities. Unique optimal solutions to the models occur as long as the utility function satisfies the conditions mentioned above. The distinction between the models is whether a single quality measure or vector is associated with each good. Cox and Wohlgenant (1986) present a recent application of this approach to food consumption.

Lancaster

Perhaps the better known of the two theoretical approaches is that developed by Lancaster (1966, 1971). Utility in this model is derived exclusively from the attributes of goods. Continuity, convexity, and declining marginal utility are conditions imposed on the utility function. The consumption technology is the relationship between types and amounts of characteristics contained in the goods. It is considered to be exogenous to a consumer. Consumer decision making centers on the selection of an optimal bundle of characteristics given the consumption technology, income, and prices of goods. Within this framework goods with differing levels of characteristics are treated as separate goods. Price and quality are not determined simultaneously as in the Houthakker-Theil model (Hanemann 1982).

Three assumptions associated with the consumption technology are needed to ensure a unique optimal consumption bundle. First, every characteristic must yield nonnegative marginal utility, or NMU (Hendler 1975). Second, utility must be independent of the distribution of characteristics, or IDC, among products (Ladd 1982). Third, there is a linear consumption technology, or LCT (Lucas 1975).

Consumer Goods Characteristics Model

Suvannunt (1973) and Ladd and Suvannunt (1976) developed a variant of the Lancaster model that does not employ the NMU condition. It has been extended further by Eastwood, Brooker, and Terry (1986); Eastwood, Gray, and Brooker (1986); Hager (1985); LaFrance (1983); and Terry (1985). The particular version presented below is Ladd and Suvannunt's because their model is most suitable for the Box-Cox methodology used subsequently to test the theoretical constraints. It is called the consumer goods characteristics model (CGCM).

Utility is derived by the consumer from characteristics. Two types of characteristics are defined. Common characteristics are those that are present in two or more goods. A unique characteristic is one that is specific to a single good. Each good is considered to have a unique characteristic and common characteristics. NMU is replaced by the assumption that a good may have a characteristic that yields a negative marginal utility, but an increase in the good must still yield a net positive change in utility over all the attributes it possesses.

$$U = u(X_1,\dots,X_m,X_{m+1},\dots,X_{m+n}). \tag{1}$$

m = the number of common characteristics;

X_j = the amount of the jth characteristic consumed.

The level of the jth attribute is a function of the quantities of goods consumed and the amounts of attributes present in the goods. This is the consumption technology.

$$X_j = X_j(q_1,\dots,q_n,x_{1,j},\dots x_{n,j}), \text{ for } j = 1,\dots,m. \tag{2}$$

$$X_{m+i} = X_{m+i}(q_i,x_{m+i}), \text{ for } i = 1,\dots,n. \tag{3}$$

$x_{i,j}$ = the amount of the jth attribute found in the ith good.

Given a one-period analysis, the consumer has a fixed budget to spend on goods.

$$M = \sum_{i=1}^{n} p_i\, q_i. \tag{4}$$

M = money income.

The consumer's decision is to choose the bundle of q_i's that maximizes the utility derived from attributes given the consumption technology, preferences, income, and prices. Substitute (2) and (3) into (1) to obtain utility as a function of the quantities of goods purchased.

$$U = u(q_1,\dots,q_n,x_{1,1},\dots,x_{n,m+n}). \tag{5}$$
$$= u(\cdot).$$

The constrained maximization problem is shown as:

$$L = U + \lambda\,(M - \sum_{i=1}^{n} p_i\, q_i), \text{ for } i = 1,\dots,n. \tag{6}$$

The first order conditions are

$$\partial L/\partial q_i = U_i - \lambda p_i = 0, \text{ and} \tag{7}$$

$$\partial L/\partial \lambda = M - \sum_{i=1}^{n} p_i\, q_i = 0.$$

$$U_i = \partial U(\cdot)/\partial q_i.$$
$$= (\partial U/\partial X_j)\,(\partial X_j/\partial q_i) + (\partial U/\partial X_{m+i})\,(\partial X_{m+i}/\partial q_i). \tag{8}$$

Substituting (8) into (7) and rearranging yields:

$$p_i = (1/\lambda)[\sum_{j=1}^{m}(\partial U/\partial X_j)(\partial X_j/\partial q_i) + (\partial U/\partial X_{m+i})(\partial X_{m+i}/\partial q_i)]. \tag{9}$$

Since λ is the marginal utility of money,

$$p_i = \sum_{j=1}^{m} (\partial X_j / \partial q_i)(\partial U / \partial X_j)(\partial I / \partial U) + (\partial X_{m+i} / \partial q_i)(\partial U / \partial X_{m+i})(\partial I / \partial U). \qquad (10)$$

This is the hedonic price equation. It relates the market price the consumer pays for the ith good to the changes in utility associated with a unit change in the respective good. The changes can be separated into the effect of a change in q_i on the amount of the jth attribute consumed, the marginal utility of the jth attribute, and the reciprocal of the income effect of the price change. These apply to both the common and unique attributes.

A Set Theory Analysis of CGCM's Hedonic Price Equation

CGCM can be analyzed as a mathematical programming problem. The approach is based upon work by Intrilligator (1971) that to date has not been applied to the CGCM model. Let bold symbols without subscripts denote respective vectors of appropriate dimensions in Euclidean space. The problem is to maximize

$$U = u(\mathbf{X}), \qquad (11)$$

subject to:

$$\mathbf{X} = \mathbf{X}(\mathbf{q},\mathbf{x}). \qquad (12)$$

$$M = \mathbf{p}'\mathbf{q}. \qquad (13)$$

X is considered to be a feasible solution if it satisfies all the constraints, and there may be several of these vectors. $\mathbf{X}^s$ is defined as the set of all feasible vectors. The problem is to identify the $\mathbf{X} \in \mathbf{X}^s$ that maximizes (11). Let $\mathbf{X}^*$ be a feasible vector. It is a global maximum if it obtains a value for (11) that is greater than or equal to that from any other $\mathbf{X}^*$, or:

$$\mathbf{X}^* \in \mathbf{X}^s \text{ and } U(\mathbf{X}^*) \geqslant U(\mathbf{X}) \text{ for all } \mathbf{X} \in \mathbf{X}^s. \qquad (14)$$

The global maximum is a strict maximum if the value of (11) is strictly larger than that for any other $\mathbf{X}^*$. A strict maximum is unique.

$$U(\mathbf{X}^*) > U(\mathbf{X}^s). \qquad (15)$$

A feasible vector is a local maximum as long as it yields a value of the utility function larger than or equal to that obtained by any other feasible vector sufficiently close to it.

$$\mathbf{X}^* \in \mathbf{X}^s \text{ and } U(\mathbf{X}^*) \geqslant U(\mathbf{X}) \text{ for all } \mathbf{X} \in \mathbf{X}^s \;\; N(\mathbf{X}^*), \qquad (16)$$

$$N(\mathbf{X}^*) = \text{the neighborhood of } \mathbf{X}.$$

The local maximum is a strict maximum if the value of (11) is strictly larger than that for any other $\mathbf{X}^*$ for $N(\mathbf{X}^*)$.

$$U(\mathbf{X}^*) > U(\mathbf{X}) \text{ for all } \mathbf{X}\epsilon\mathbf{X}^s \;\; N(\mathbf{X}^*). \tag{17}$$

The local-global theorem gives sufficient conditions for a local maximum to be a global maximum. If the opportunity set $\mathbf{X}^s$ is a nonempty compact set that is convex and $U(\mathbf{X})$ is a continuous function that is concave over $\mathbf{X}$, then a local maximum is a global maximum. This ensures that the set of values at the maximum is convex. When (11) is strictly concave over $\mathbf{X}$ and $\mathbf{X}^s$ is convex, a local maximum is a unique strict global maximum.

The Weierstrass theorem gives the sufficient conditions for the existence of a global maximum. $\mathbf{X}^s$ must be compact (i.e., closed and bounded), nonempty, and $U(\mathbf{X})$ continuous over $\mathbf{X}^s$. These conditions are the equivalent of assuming that (11) is continuous and increases at a decreasing rate. U is positive and increases as X_j increases. Thus, the change in U, marginal utility, must be positive and progressively smaller, which is referred to as decreasing marginal utility.

Figure 1 illustrates these conditions. Panel (a) shows the utility function to be strictly concave over OX_j^*, the feasible range of attribute j given the consumption technology, income, prices, and levels of other attributes. OX_j^* is compact since the feasible region has a well-defined boundary. It is also a nonempty set. Any chord connecting two points on U (e.g., AB) lies below U, so the utility function is convex. Panel (b) displays the slope of the total utility function, or the marginal utility. Given the constraints on total utility, marginal utility must be positive and approach zero as X_j increases. The second derivative of the utility function, Panel (c), ensures that marginal utility is declining.

The Previous CGCM Hedonic Price Equation Approach to Estimation

Empirical work based upon CGCM has focused on food demand. Restriction to a subset of characteristics necessitates the imposition of two assumptions. First, food is assumed to be separable from all other consumer goods. Second, food nutrients are considered to be separable from other food characteristics. Together, they allow one to model consumer decision making for food nutrients independently of other attributes and goods. As a result, the rest of the discussion uses the same notation, but it pertains to the food sector.

Another convenient condition to employ is that of a linear consumption technology. More specifically, the marginal effect on the level of a nutrient consumed due to a change in the amount of a particular food item is constant. For example, the change in the amount of calcium per ounce of milk is the same regardless of whether a person drinks a glass or a quart. With respect to the common nutrients, this is

$$\partial X_j/\partial q_i = x_{i,j}, \text{ for } j = 1,\ldots,m. \tag{18}$$

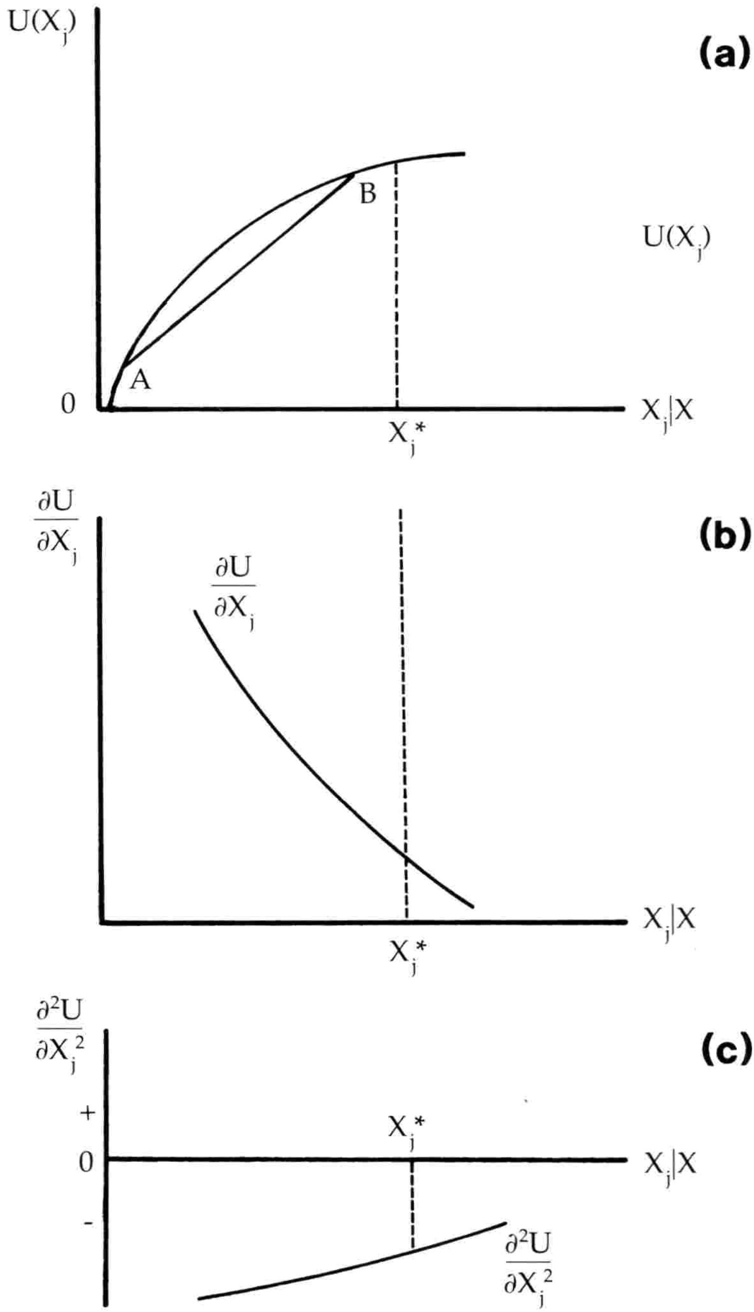

Figure 1. Total Utility, Marginal Utility, and Change in Marginal Utility.

Two other simplifying assumptions pertain to constant marginal utilities of nutrients and income, so the product of the two derivatives shown below must be constant.

$$(\partial U/\partial X_j)(\partial I/\partial U) = b_j. \tag{19}$$

Similarly, for the unique nutrients, it is assumed that an incremental change in a food is associated with a one-unit change in the unique nutrient. When combined with the assumptions of constant marginal utilities of nutrients and income, the product of these derivatives is

$$(\partial U/\partial X_{m+i})(\partial X_{m+i}/\partial q_i)(\partial I/\partial U) = b_{m+i}. \tag{20}$$

Altogether, these assumptions yield a hedonic price equation that is linear in the $x_{i,j}$ and the b_j:

$$p_i = b_{m+i} + \sum_{j=1}^{m} b_j x_{i,j}. \tag{21}$$

Interpretation of (21) is as follows. The willingness to pay for the unique nutrient is represented by b_{m+i}. The b_j are the consumer's marginal implicit prices of the respective nutrients. Therefore, the market price is a linear combination of the valuation of the unique attribute plus the sum of the constant implicit prices multiplied by the amounts of the respective characteristics. The constant marginal utility approach has been used in empirical work by Adrian and Daniel (1976); Allen and Gadson (1983); Chavas and Kepplinger (1983); Davis and Neenan (1979); Eastwood (1989); Eastwood, Brooker, and Terry (1986); Eastwood, Gray, and Brooker (1986); Hager (1985); Ladd and Suvannunt (1976); Ladd and Zober (1977); Lane (1978); LaFrance (1983); Price *et al.* (1976); Searce and Jensen (1979); and Terry (1985).

The approach taken in food demand is similar to that of hedonic analyses of other market goods. Traditional approaches have assumed that there is no theoretical ground for any specific functional form. Examples include Bender, Gronberg, and Huang (1980), Halvorsen and Pollakowski (1981), Jordan *et al.* (1985), and Rosen (1974).

A Box-Cox Hedonic Price Equation for CGCM and the Theoretical Constraints

The problem in the transformation of (10) into (21) is that the assumption of constant marginal utility is inconsistent with the conditions for a unique maximum. However, it can be avoided through the use of the Box-Cox functional form. Returning to (10), an estimable equation can be derived in the following manner.

LCT is still maintained, since this condition is suitable for foods. A unit of each food is assumed to generate a unit of its unique attribute. The assumption of a constant marginal utility of income is maintained, and this is consistent with a unique solution. Marshall (1920) introduced the idea of constant marginal utility of income in the derivation of classical demand curves in which he assumed that small changes in the prices of products do not change real income for products that form a small portion of the consumer's budget. Friedman (1949) argues that the type of demand Marshall had in mind was one in which real income was held constant. Both interpretations are consistent with the notion of $(\partial U/\partial I)$ being constant (McConnell and Phipps 1985).

These considerations mean that the relationship between p_i and the nutrients depends primarily on their marginal utilities. Since the p_i are positive, $x_{i,j}$ is nonnegative, and $(\partial U/\partial I)$ is positive, $(\partial U/\partial X_j)$ must be positive. Furthermore, positive declining marginal utility implies that p_i increases at a decreasing rate.

Many functional forms for the hedonic price equation can be created that are consistent with a unique nutrient consumption bundle. Among them are the double-log, semi-log, reciprocal, and log-reciprocal. These are shown in Figure 2. All are characterized as being positive, and all increase at decreasing rates.

Theoretically, no criterion exists for preferring one of these relationships over another. Consequently, a way to proceed is to choose a general functional form that has the explicit possibilities as special cases. The double Box-Cox transformation is used in this study and is shown below.

$$p_i^* = b_o + \sum_{j=1}^{m} b_j x_{i,j}^{**}. \tag{22}$$

$$p_i^* = (p_i^{\lambda} - 1)/\lambda.$$

$$x_{i,j}^{**} = (x_{i,j}^{\mu} - 1)/\mu.$$

To ensure that p_i is nonnegative and increases at a decreasing rate, (22) needs to be rearranged and its first and second derivatives evaluated. These are shown below.

$$\partial p_i/\partial X_j = p_i^{(1-\lambda)} b_j x_{i,j}^{(\mu-1)}. \tag{23}$$

$$\partial^2 p_i/\partial X_j^2 = (\mu-1)p_i^{(1-\lambda)} b_j x_{i,j}^{(\mu-2)} + b_j^2(x_{i,j}^{\mu-1})^2(p_i^{1-2\lambda})^2(1-\lambda). \tag{24}$$

The first partial, (23), should be positive. Neither transformation parameter affects the sign of the first partial. Given the assumptions about p_i and $x_{i,j}$, (23) is positive. An interpretation is that as more of a nutrient is present, the consumer should be willing to pay more. The second partial imposes additional restrictions. Several possibilities exist in order for (24) to be negative. These are listed in Table 1, where Z denotes the first expression on the right side of (24), and W denotes the second. Figure 3 presents a general representation of (22)–(24) that conforms to the theory.

Table 2 presents commonly estimated hedonic price equation forms and shows the values of the transformation parameters and coefficients associated with each. In light of Table 1, four out of five explicit forms are

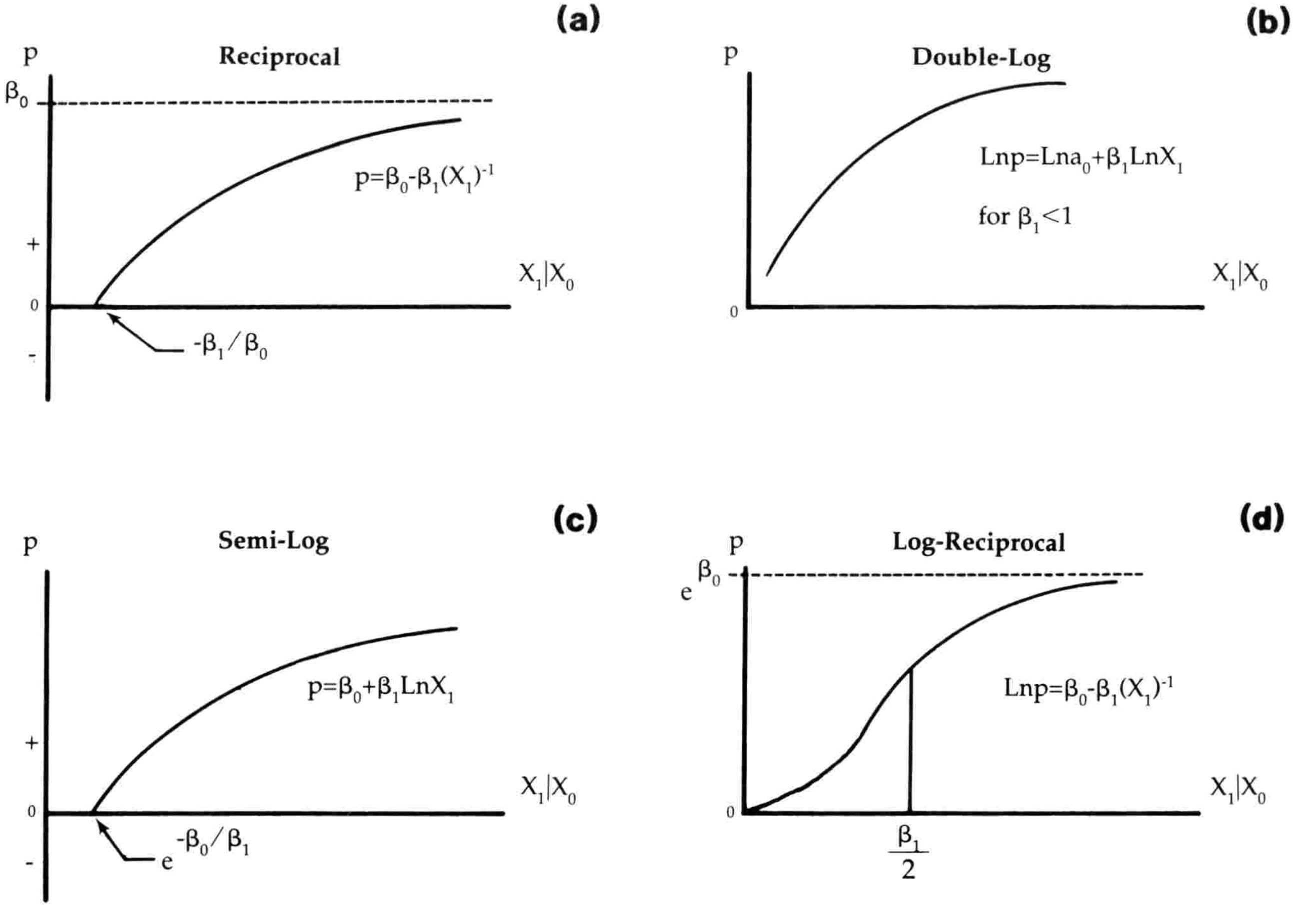

Figure 2. Functional Forms that Display Declining Marginal Utility.

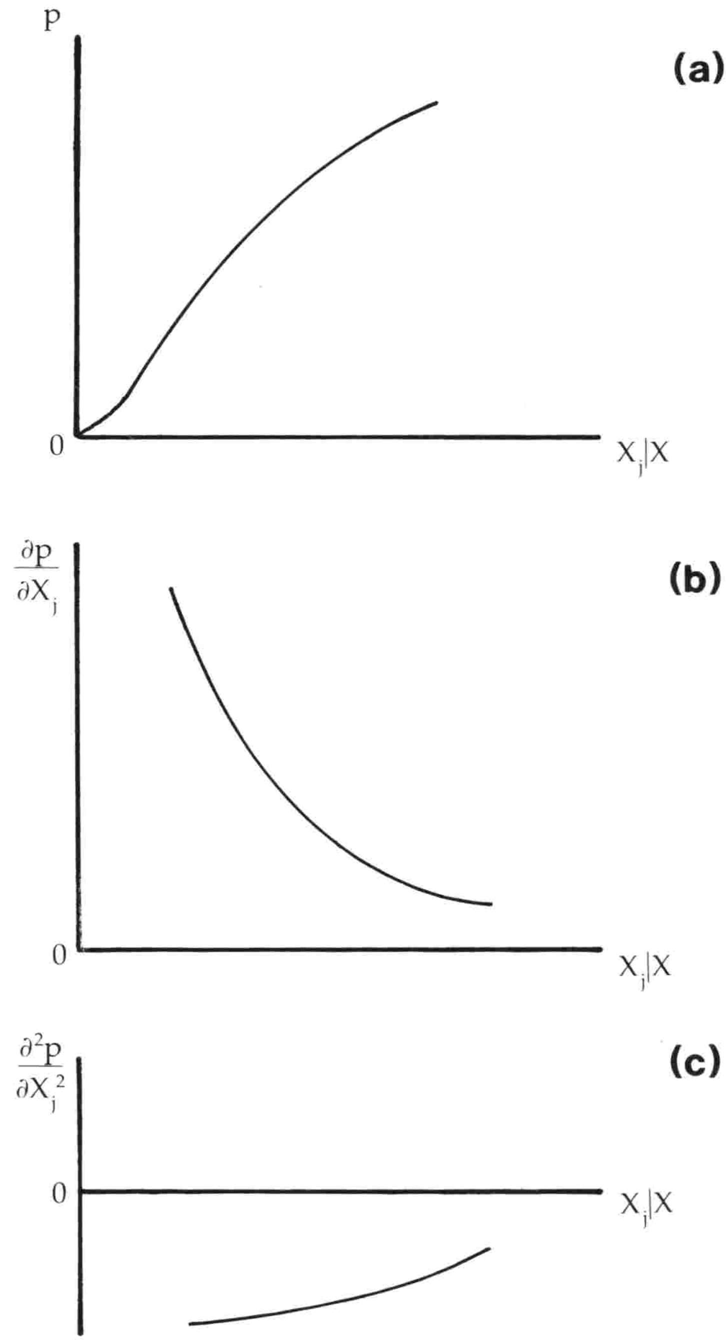

Figure 3. The Hedonic Price Equation.

consistent with the theoretical constraints. The exception is the linear form because the values of λ and μ fall outside the bounds shown in Table 1. Equation (22) can be estimated in order to test whether theoretical conditions hold. The remainder of this bulletin focuses on empirical issues associated with estimation and the results of some preliminary tests.

Table 1. Second-order Restrictions on the Box-Cox Hedonic Price Equation

	b_j	λ	μ	Z	W and Z
(A)	$b_j>0$	≥ 1	<1		
(B)	$b_j>0$	>1	≤ 1		
(C)	$b_j>0$	<1	<1	<0	$W<\lvert Z\rvert$
(D)	$b_j>0$	>1	>1		$Z<\lvert W\rvert$

Table 2. Box-Cox Parameter Values for Frequently Used Forms and Their Relationships to the Second-order Conditions

Form	Equation	b_j	λ	μ	Condition Met
Linear	$p_i = b_o + \sum_{j=1}^{m} b_j x_{i,j}$	>0	1	1	No
Double-log	$Lnp_i = Lnb_o = \sum_{j=1}^{m} b_j Lnx_{i,j}$	>0	0	0	Yes
Semi-log	$p_i = b_o = \sum_{j=1}^{m} b_j Lnx_{i,j}$	>0	1	0	Yes
Reciprocal	$p_i = b_o - \sum_{j=1}^{m} b_j x_{i,j}^{-1}$	<0	0	-1	Yes
Log-reciprocal	$Lnp_i = b_o - \sum_{j=1}^{m} b_j x_{i,j}^{-1}$	<0	0	-1	Yes

Data

The 1977-78 Nationwide Food Consumption Survey (NFCS) can be used to estimate (22) at the household level. This survey was conducted by the U.S. Department of Agriculture to obtain information about the food purchases and food use by a representative sample of American households and by a sample of low income households. Foods that were obtained from home production or gifts were included and valued at prevailing regional prices. Both the cost of foods and the quantities used are recorded, so it is possible to determine the price of each food item used by a household. Approximately 15,000 households are included in the entire survey.

Only the spring quarter of the survey is used in the present analysis. It would be too costly to estimate the hedonic price equation for each of the households. Restricting the empirical work to a single quarter has the advantage of avoiding seasonal variations in consumption and prices.

Household members who were most responsible for food planning and meal preparation were interviewed. These people were contacted seven days prior to the actual interview and asked to keep grocery receipts, shopping lists, menus, labels, or anything else that could help recall the foods consumed during the seven-day period. Interviewers recorded the kind, form, quantity, and cost of foods and beverages actually consumed by the household at home. Other data collected include food produced at home, the number of meals eaten at home and away by household members, food eaten by guests, and socioeconomic information.

Food use in this survey refers to economic consumption, as opposed to physiological consumption. That is, the data represent the allocation of income for consumption for purposes of the operation of the vital process of living. Nutritional values were adjusted for loss due to meal preparation. Some foods could be discarded at the table, however, thereby causing the consumption of nutrients to be overestimated. The consumption of nutrients could also be understated due to meals eaten away from home and the use of nutrient supplements.

The amounts of fourteen nutrients in each food are included in the data. These are protein, fat, carbohydrates, calcium, iron, magnesium, phosphorus, vitamin A, thiamin, riboflavin, niacin, vitamin B_6, vitamin B_{12}, and vitamin C. Food energy is also available. It is a linear combination of protein, fat, and carbohydrates.

Several adjustments in the data had to be made. First, Terry (1985) found a high degree of pairwise collinearity among some nutrients. He found that aggregating these nutrients reduced the correlations among the remaining nutrients to very low levels. Consequently, the work reported here commenced by performing similar aggregations. The "minerals" category is the sum of calcium, iron, magnesium, and phosphorus consumption in milligrams. Thiamin, riboflavin, niacin, vitamin B_6, and vitamin B_{12} consumption, in milligrams, are combined into the "B-complex" category. These aggregations are consistent with the view that consumers are concerned with broader groups of nutrients (Weimer 1980). It reduced the number of nutrients from fourteen to seven.

Inspecting household food use records revealed that many of the food items contained zero levels of at least one of the seven nutrients. This is not surprising because only a few foods are well balanced in terms of providing all nutrients. However, zero values pose a problem for the Box-Cox estimation process because transformations when $x_{i,j}$ equals zero are undefined. The problem was resolved by further aggregation and omitting one nutrient. These aggregations are considered to be consistent with the view that consumers are concerned with broader groups of nutrients (Weimer 1980).

Vitamin A was deleted. It is measured in international units, so it could not be combined directly with the other vitamins. Its omission is consistent with the results of Eastwood (1989); Eastwood, Gray, and Brooker (1986); and Eastwood, Brooker, and Terry (1986). Furthermore, vitamin A is found in only a few foods and when present is in large quantities relative to recommended daily allowances.

Two additional aggregates were generated. Since vitamin C also is not present in many foods, and since it is measured in milligrams, it was combined with the B-complex to generate a single vitamin variable. One value for food energy was used instead of individual values for protein, fat, and carbohydrates.

Three aggregated nutrients, then, comprise the $x_{i,j}$ for (22). They are vitamins, minerals, and food energy. Two points need to be stressed. First, since interest centers on whether the data support the assumption of declining marginal utility, attention is focused on the overall hedonic price equation as opposed to specific nutritional relationships. Second, to the extent that consumers are considered to be concerned with broader groups of nutrients, the aggregations reflect decision-making measures.

Approximately 3,300 households are included in the spring quarter of the NFCS survey. Elimination of households with incomplete records reduced the sample to 2,164 households. Altogether, they used over 100,000 food items. This is too large a sample for Box-Cox estimation procedures, as the cost of the requisite computer time would be prohibitive. Consequently, subsamples were drawn from the spring wave. The number of food items purchased by households in the spring wave ranged from zero to 131. Households that purchased between 40 and 70 food items were drawn from the spring wave. This range was chosen to avoid those households that were either consuming a large proportion of food from stocks or were making purchases that seemed to replenish them. Three different types of household samples that met the above criterion were drawn from the spring wave.

One subsample was drawn to accommodate regional differences in food consumption. Two households from each of the four regions

(Northeast, North Central, South, and West) were selected. Equation (22) was estimated for each household and for the pooled regions. Table 3 presents summary food information for this subgroup. This sample was used to generate individual household-level estimates and to obtain a "feel" for the data and the estimation algorithm to ensure that it could handle some larger groups in subsequent estimation steps.

A second regional subsample was drawn that was somewhat larger. Six households from each region that met the food purchase criterion were drawn. Pooled regressions were calculated for each region and for the entire sample. Table 4 presents food purchase information for this subsample.

The third sample was drawn to accommodate differences in household income. As income changes, the household's ability to purchase foods can change, and this could lead to different valuations of nutrients. Households in the spring wave were ranked on the basis of their per capita incomes plus the bonus values of food stamps used. Six households from each quartile that purchased 40 to 70 food items were randomly selected. Table 5 presents food purchase information for this subsample. Pooled regressions were calculated for each quartile and for the entire sample.

Each household drawn from the sample purchased five or fewer food items that contained a zero value for one of the three nutrient aggregates described above. This necessitated dropping these foods. Since the number of such food items is small, the omissions should lead to a minimal selection bias.

Table 3. Initial Regional Sample: Food Purchases by Household

Region	Household	Number of Foods Purchased
Northeast	A	63
	B	66
North Central	A	59
	B	53
South	A	73
	B	47
West	A	59
	B	59
		479

Results

A Box-Cox regression program developed by Huang, Moon, and Chang (1978) was used to estimate (22). It performs a grid search over values of λ and μ from -1.6 to 1.6 by increments of 0.1. Because the maximum likelihood estimates reported below fall well within these bounds, there was no need to alter the end points. The grid search involves generating the transformed variables p_i^* and $x_{i,j}^{**}$ and calculating least squares regressions. The estimated equation that has the largest likelihood value is the maximum likelihood estimate (MLE).

It is also possible to test the hypothesis that the estimates associated with a specific functional form are not significantly different from the MLE

Table 4. Expanded Regional Sample: Food Purchases by Household

Region	Household	Number of Foods Purchased
Northeast	A	46
	B	48
	C	51
	D	42
	E	64
	F	46
		297
North Central	A	56
	B	44
	C	46
	D	53
	E	49
	F	45
		293
South	A	55
	B	51
	C	51
	D	55
	E	41
	F	51
		304
West	A	56
	B	49
	C	62
	D	48
	E	61
	F	53
		329

Table 5. Income Quartile Sample: Food Purchases by Household

Quartile	Household	Number of Foods Purchased
Lowest	A	48
	B	39
	C	41
	D	47
	E	43
	F	50
		268
Second	A	51
	B	53
	C	47
	D	41
	E	51
	F	44
		287
Third	A	41
	B	41
	C	49
	D	56
	E	49
	F	48
		284
Highest	A	43
	B	40
	C	46
	D	49
	E	46
	F	48
		272

point estimates. Notice that the grid search automatically generates estimates of the five functional forms listed in Table 2. The null hypothesis is that there is no difference between the MLE point estimates and those of a specific functional form. The alternative hypothesis is that the difference is significant. Theil (1971) shows that is a likelihood ratio test of the form

$\Phi = [L^*(\lambda,\mu)/L(\lambda,\mu)]$.

L^* = log likelihood value of a specified model.

L = log likelihood value of the unrestricted MLE.

Table 6 presents the likelihood values and λ and μ estimates for the specific functional forms and the MLEs for the initial regional sample.

Table 6. Values of the Restricted and Unrestricted Maximum Likelihood Functions of the Hedonic Price Equation for the Initial Sample

		Restricted					Unrestricted	
Region/House		LnL(1.0,1.0)[a] linear	LnL(0.0,0.0) double-log	LnL(1.0,0.0) semi-log	LnL(1.0,-1.0) reciprocal	LnL(0.0,-1.0) log-reciprocal	LnL($\hat{\lambda}$,$\hat{\mu}$)	($\hat{\lambda}$,$\hat{\mu}$)
Northeast	A	44.875	61.776*	49.858	43.030	52.981	63.099	(0.2,0.0)
	B	-22.152	37.053*	-27.425	-30.848	26.563	38.611	(-0.1,0.1)
North Central	A	6.621	48.851*	7.240	5.918	44.777	49.664	(-0.1,0.1)
	B	36.463	46.037*	38.348	34.766	42.716*	46.722	(0.2,0.0)
South	A	32.543	57.237*	30.763	25.024	49.746	58.289	(0.0,0.3)
	B	5.665	44.335*	6.481	6.497	43.579*	47.483	(-0.4,0.0)
West	A	17.985	46.331*	16.131	11.584	42.695*	46.442	(0.0,0.1)
	B	35.762	64.017*	36.240	33.418	62.666*	64.590	(-0.1,0.6)
Pooled sample		75.473	396.645*	78.559	58.266	358.016	397.815	(-0.1,0.1)

*Significant functional form at .05 level.
[a]Estimates in parentheses are λ and μ respectively.

With the exception of the double-log form, the MLEs are significantly different. Since the MLEs, by definition, comprise the best set of point estimates for the sample, the inference to be drawn is that the various functional forms do not provide statistically comparable estimates to the MLEs. Thus, it is appropriate to proceed with the Box-Cox regression technique and not resort to specifying a functional form for the hedonic price equation *a priori*.

The complete set of MLEs for the initial subsample are shown in Table 7. Since interest centers on the presence of declining marginal utility, interpretation of the individual coefficients is treated briefly. The "vitamins" category always has a coefficient that is not significantly different from zero, which suggests that this broad group of nutrients does not affect consumers' valuations of foods. Equations for minerals and food energy generally have positive significant coefficients. The computed R^2s are not unexpected given the household-level, cross-sectional data.

Declining marginal utility holds as long as (23) and (24) obtain values that are within the ranges specified in Table 1. For the significant coefficients, case (c) is the appropriate test. In each instance the computations generate values of Z that are negative, and the associated value of W is less than the absolute value of Z. The inference to be drawn is that the estimated MLE equations for each household and the entire subsample are consistent with declining marginal utility.

Since the initial subsample generated significant results and the Box-Cox algorithm yielded estimates without using much computer time, it seemed appropriate to create other somewhat larger subsamples to test for declining marginal utility. This prompted selection of the two additional subsamples described in the preceding section. Analyses of the results are outlined below.

In the interest of dealing with a larger sample and based upon the results from the initial subsample, the Box-Cox algorithm was applied only to the 6 pooled households for each region and for the entire 24 households in the expanded regional sample. Results are found in Table 8. Aside from the one exception of vitamins in the West, each of the marginal implicit prices has a significant positive estimate. The MLEs, including the transformation parameters, are consistent with declining marginal utility associated with case (c) in Table 1. The overall fits, as represented by the R^2s, are reasonably high.

Direct comparisons of the coefficients are not possible. Since the transformation parameters are different, the functional relationships are different. However, it is possible to make comparisons via (23). This equation defines the marginal valuations of the nutrients across the set of Box-Cox functional forms. Using average sample values for p_i and $x_{i,j}$ and the estimated set of parameters, these valuations are shown in Table 9 for the significant coefficients. Inspection of this table reveals that vitamins have the highest marginal effects, and the pattern of values between

Table 7. Hedonic Price Equation Estimates for the Initial Sample (t values in parentheses)

Region/House		β_0 intercept	β_1 vitamin BC	β_2 minerals	β_3 food energy	R^2	$(\hat{\lambda},\hat{\mu})$
Northeast	A	-3.277	0.076	0.213	0.220		
		(-6.428)*	(1.415)	(4.035)*	(3.206)*	.397	(0.2,0.0)
	B	-3.081	0.014	0.191	0.115		
		(-5.861)*	(0.344)	(4.819)*	(2.431)*	.397	(-0.1,0.1)
North Central	A	-2.764	-0.005	0.123	0.113		
		(-4.936)*	(-0.107)	(2.746)*	(1.995)*	.243	(-0.1,0.1)
	B	-2.318	-0.066	0.148	0.185		
		(-3.875)*	(-1.027)	(2.116)*	(2.423)*	.225	(0.2,0.0)
South	A	-1.937	0.033	0.039	0.027		
		(-5.935)*	(1.382)	(3.701)*	(2.258)*	.306	(0.0,0.3)
	B	-3.550	0.075	0.215	0.174		
		(-3.456)*	(0.795)	(2.150)*	(1.294)	.118	(-0.4,0.0)
West	A	-2.886	-0.025	0.120	0.152		
		(-4.652)*	(-0.471)	(2.882)*	(2.476)*	.274	(0.0,0.1)
	B	-1.40	0.008	0.002	0.004		
		(-5.777)*	(1.208)	(1.312)	(1.991)*	.094	(-0.1,0.6)
Pooled sample		-2.709	0.013	0.127	0.112		
		(-13.876)*	(0.728)	(8.219)*	(6.125)*	.267	(-0.1,0.1)

*Significant at .05 level.

Table 8. Hedonic Price Equation Estimates by Expanded Region (t values in parentheses)

Variable	Region				
	North-east	North Central	South	West	Total
Constant	-2.046* (-11.955)	-2.116* (-13.043)	-2.620* (-10.16)	-3.343* (-11.33)	-2.808* (-22.330)
Vitamins	.044* (4.401)	.027* (2.75)	.041* (1.973)	-.022 (-.790)	.037* (3.463)
Minerals	.030* (5.487)	.036* (6.205)	.083* (4.267)	.226* (6.956)	.110* (11.267)
Food energy	.032* (4.690)	.034* (5.410)	.134* (5.820)	.228* (5.471)	.128* (10.782)
R^2	.23	.27	.19	.30	.25
L	252.92	264.90	249.12	246.31	1,008.93
λ	-.1	-.1	0.0	-.1	-.1
μ	.3	.3	.1	0.0	.1
n	297	293	304	329	1,223

*Significant at .05 level.

Table 9. Marginal Implicit Prices: Expanded Regional Sample (cents per dollar)*

Region	Vitamins	Minerals	Food Energy
Northeast	.215	.021	.021
North Central	.130	.025	.023
South	.088	.015	.022
West		.018	.019
Pooled sample	.084	.002	.002

*Based on significant coefficients in Table 8.

minerals and food energy is mixed.

Results of the income subgroup estimates are shown in Table 10. All of the significant coefficients are positive. Only vitamins for the second and top quartiles are not significant. Each set of MLEs is consistent with declining marginal utility shown for case (c) in Table 1. The R^2s are fairly high for household-level, cross-section data. Table 11 presents the marginal valuations based upon (23). The pattern is similar to the regional results in that vitamins have the largest values and that the relationship between minerals and food energy is not consistent. Another important point is that the valuations of nutrients do not decline as income rises. Two factors could be involved with this result. One is that households could be substituting other sources of foods as income rises. Specifically, households could be eating more food away from home as income rises, thereby leading to no systematic decline in the marginal effect. The second is that other socioeconomic variables affect the position of the efficiency frontier such as sources of income, race, and the age distribution of members. Focusing on income alone may be insufficient as a result.

Table 10. Hedonic Price Equation Estimates by Income Groups (t values in parentheses)

Variable	Income				
	Lowest	Second	Third	Highest	Total
Constant	-2.743* (-10.300)	-3.394* (-11.473)	-2.290* (-13.616)	-2.205* (-14.150)	-2.268* (-23.94)
Vitamins	.064* (3.15)	.004 (.131)	.032* (3.205)	.003 (.255)	.033* (3.267)
Minerals	.087* (4.363)	.235* (6.706)	.036* (5.935)	.067* (7.741)	.114* (11.792)
Food energy	.133* (5.506)	.213* (5.163)	.038* (5.776)	.065* (6.500)	.125* (11.366)
R^2	.22	.28	.29	.39	.29
L	220.70	244.89	249.32	259.45	962.81
λ	0	-.1	-.1	.1	0.0
μ	.1	0.0	.3	.2	.1
n	268	287	284	272	1111

*Significant at .05 level.

Table 11. Marginal Implicit Prices: Income Quartile Sample (cents per dollar)*

Quartile	Vitamins	Minerals	Food Energy
Lowest	.119	.014	.021
Second		.020	.018
Third	.141	.025	.025
Highest		.021	.021
Pooled sample	.066	.019	.020

*Based on significant coefficients in Table 10.

Summary and Implications

This research has established the requisite theoretical ties between a unique optimal solution to the utility maximization problem in CGCM and the estimation of the hedonic price equation. The functional form of the latter reflects declining marginal utility via increasing at a decreasing rate in order to be theoretically correct. The Box-Cox functional form of the hedonic price equation generates the requisite relationship for restricted values of its parameters. The ensuing empirical question is whether estimates of the Box-Cox hedonic price equation generate values that are consistent with the conditions shown in Table 2.

Subsamples drawn from the NFCS consistently estimate the equation within the theoretical constraints, so the data support the assumption of declining marginal utility.

Several implications can be drawn. First, empirical work with CGCM, in particular, and characteristics models, in general, should use a functional form of the hedonic price equation that is consistent with declining marginal utility. Second, the results support the characteristics model approach to the study of food consumption. Consumers do value broad aggregates of nutrients. This suggests that promotional opportunities exist and that food marketers can effectively promote products by referring to broad aggregates of nutrients. Nutrition-based advertisements need not be regional in nature nor directed toward specific income groups. Researchers and policy analysts in assessing diets and dietary change have further indications that vitamins vis-a-vis minerals and food energy are more highly valued. Attempts to bring about dietary change could focus on broad aggregates and need not be restricted to specific income levels or regions.

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